High School Chemistry Standards and Learning Activities

SCIENTIFIC INVESTIGATION AND INQUIRY

C.1. Broad Concept: Scientific progress is made by asking relevant questions and conducting careful investigations. As a basis for understanding this concept, and to address the content in this grade, students should develop their own questions and perform investigations.

Students:

1. Know the elements of scientific methodology (identification of a problem, hypothesis formulation and prediction, performance of experimental tests, analysis of data, falsification, developing conclusions, reporting results) and be able to use a sequence of those elements to solve a problem or test a hypothesis. Also, understand the limitations of any single scientific method (sequence of elements) in solving problems.
2. Know that scientists cannot always control all conditions to obtain evidence, and when they are unable to do so for ethical or practical reasons, they try to observe as wide a range of natural occurrences as possible so as to be able to discern patterns.
3. Recognize the cumulative nature of scientific evidence.
4. Recognize the use and limitations of models and theories as scientific representations of reality.
5. Distinguish between a conjecture (guess), a hypothesis, and a theory as these terms are used in science.
6. Plan and conduct scientific investigations to explore new phenomena, to check on previous results, to verify or falsify the prediction of a theory, and to use a crucial experiment to discriminate between competing theories.
7. Use hypotheses to choose what data to pay attention to and what additional data to seek, and to guide the interpretation of the data.
8. Identify and communicate the sources of error inherent in an experiment.
9. Identify discrepant results and possible sources of error or uncontrolled conditions.
10. Select and use appropriate tools and technology to perform tests, collect data, analyze relationships, and display data. (The focus is on manual graphing, interpreting graphs, and mastery of metric measurements and units, with supplementary use of computers and electronic data gathering when appropriate.)
11. Formulate and revise explanations using logic and evidence.
12. Analyze situations and solve problems that require combining concepts from more than one topic area of science and applying these concepts.
13. Apply mathematical relationships involving linear and quadratic equations, exponential growth and decay laws, and logarithmic relationships to scientific situations.
14. Recognize and deal with the implications of statistical variability in experiments, and explain the need for controls in experiments.

Examples *Students construct models of atoms and then diagram the experimental apparatus that scientists used to advance the knowledge of the atom (e.g., Rutherford highlighted the discovery of the nucleus by shooting helium nuclei at a thin sheet of gold) (C.1.3).*

Students evaluate scientists' use of empirical and experimental evidence in the progression of knowledge of the atom and its properties (C.1.5).

SCIENTIFIC INVESTIGATION AND INQUIRY (CONTINUED)

Students evaluate the levels of chemical pollutants (such as phosphates, nitrates, chlorides) in tap water, the Rock Creek River, or the Anacostia River. They compare their data with those published in literature (C.1.6).

Students investigate a certain air pollutant, such as SO_2, CO_2, or NO_2, and the proposed effects that pollutant has for global warming (C.1.7).

Students test and compare the pollutants in rainwater, tap water, bottled water, local water sources, or waters from DC rivers with a spectrophotometer, computer-linked probes, and pH meters. They compare concentrations using bar graphs and log graphs (C.1.10).

Students design scientific investigations to test which household cleaners (Lysol, Pine-sol, Ajax, or ammonia) kill more microbes (bacteria, fungi). Students conduct the investigation following proper scientific procedures and present findings to appropriate DC environmental organizations. See www.earthforce.org for contacts (C.1.11).

Students investigate the effects of temperature on the solubility of some common household substances (salt, sugar, and Epsom salt). Students analyze and explain their results with a table and a graph (C.1.13).

PROPERTIES OF MATTER

C.2. Broad Concept: Physical and chemical properties can be used to classify and describe matter. As a basis for understanding this concept,

Students:

1. Investigate and classify properties of matter, including density, melting point, boiling point, and solubility.
2. Determine the definitions of and use properties such as mass, volume, temperature, density, melting point, boiling point, conductivity, solubility, and color to differentiate between types of matter.
3. Know the concept of a mole in terms of number of particles, mass, and the volume of an ideal gas at specified conditions of temperature and pressure.
4. Distinguish between the three familiar states of matter (solid, liquid, and gas) in terms of energy, particle motion, and phase transitions, and describe what a plasma is.
5. Infer and explain that physical properties of substances, such as melting points, boiling points, and solubility, are due to the strength of their various types of bonds (interatomic, intermolecular, or ionic).
6. Write equations that describe chemical changes and reactions.
7. Classify substances as metal or nonmetal, ionic or molecular, acid or base, and organic or inorganic, using formulas and laboratory investigations.

Examples *Students investigate the densities of different sizes, shapes, and masses of metals (buttons, coins, ball bearings, etc.) by water displacement, using a balance, graduated cylinder, and water. They use the formula $D = M/V$ to determine the densities (C.2.1).*

Students fry a raw egg in a frying pan until the egg becomes solid. Students observe, analyze, and classify this process as either a physical change or a chemical change (C.2.2).

PROPERTIES OF MATTER (CONTINUED)

Students prepare a table consisting of some elements and compounds and align them to their respective atomic masses, molecular masses, and Avogadro's number. Students explain how the mole concept is similar to the concept of a dozen (C.2.3).

Students observe and analyze the characteristic phase changes by gently heating a beaker of ice blocks until the water begins to boil (C.2.4).

Students react a solution of either Epsom salt with a solution of sodium carbonate, or baking soda with vinegar, and then they explain what happens in words and by equation (C.2.6).

Students prepare a table that classifies a set of household substances, such as oil, bread, wood, milk, vinegar, ammonia, gold, silver, aluminum, fries, chicken, antacid, soda, etc. (C.2.7).

ACIDS AND BASES

C.3. Broad Concept: Acids, bases, and salts are three classes of compounds that form ions in water solutions. As a basis for understanding this concept,

Students:

1. Explain that strong acids (and bases) fully dissociate and that weak acids (and bases) partially dissociate.
2. Define pH as the negative of the logarithm of the hydrogen (hydronium) ion concentration, and calculate pH from concentration data.
3. Illustrate and explain the pH scale to characterize acid and base solutions: Neutral solutions have pH 7, acids are less than 7, and bases are greater than 7.
4. Describe the observable properties of acids, bases, and salt solutions.
5. Explain the Arrhenius theory of acids and bases: An acid donates hydrogen ions (hydronium) and a base donates hydroxide ions to a water solution.
6. Explain the Brønsted-Lowry theory of acids and bases: An acid is a hydrogen ion (proton) donor, and a base is a hydrogen ion (proton) acceptor.

Examples *Students research the industrial uses for strong acids, such as HCl, HBr, HI, HNO_3, $HClO_4$, $HClO_3$, and H_2SO_4 (C.3.1).*

Students investigate the kinds of animals that thrive in either acidic or basic conditions (C.3.1).

Students test the pH of some common household items, such as vinegar, ammonia, soda, tap water, Epsom salt ($MgSO_4$), orange juice, antacids, and bottled water with a pH meter and classify these items as acids, bases, or neutral (C.3.3).

Students conduct a titration experiment involving an acid and a base (vinegar and ammonia) using phenolphthalein as an indicator, and they relate it to a human condition, such as heartburn, which is associated with acid indigestion and sour stomach that requires the intake of an antacid for relief (C.3.6).

ACIDS AND BASES (CONTINUED)

Students identify acids and bases in the following reactions (C.3.6):

$$H_2O + HSO_4^- \rightleftharpoons H_3O^+ + SO_4^{2-}$$

$$H_2O + HS^- \rightleftharpoons OH^- + H_2S$$

THE ATOM

C.4. Broad Concept: An atom is a discrete unit. The atomic model can help us to understand the interaction of elements and compounds observed on a macroscopic scale. As a basis for understanding this concept,

Students:

1. Detail the development of atomic theory from the ancient Greeks to the present (Democritus, Dalton, Rutherford, Bohr, quantum theory).
2. Explain Dalton's atomic theory in terms of the laws of conservation of matter, definite composition, and multiple proportions.
3. Demonstrate and explain how chemical properties depend almost entirely on the configuration of the outer electron shell, which in turn depends on the proton number.
4. Explain the historical importance of the Bohr model of the atom.
5. Construct a diagram and describe the number and arrangement of subatomic particles within an atom or ion.
6. Describe that spectral lines are the result of transitions of electrons between energy levels.
7. Describe that spectral lines correspond to photons with a frequency related to the energy spacing between levels by using Planck's formula *($E = hv$)* in calculations.

Examples

Students compare electron configurations of simple compounds, and the varying chemical properties that result such as bleach and salt (NaOCl, NaCl), water and hydrogen peroxide (H_2O, H_2O_2), and oxygen gas and ozone (O_2, O_3) (C.4.3).

Students construct their own atoms, being careful to balance charges and particles (C.4.5).

Students perform flame tests on dissolved copper, sodium, barium, strontium, and magnesium compounds and observe the different colors produced. They compare those results with absorption spectra from stars (C.4.6).

Students choose the different kinds of EM radiation, such as X-ray, visible light, or UV, that is given off by different electron transitions, depending on the amount of energy emitted, using the equation $E = hv$ *(C.4.7).*

C.5. Broad Concept: Periodicity of physical and chemical properties relates to atomic structure and led to the development of the periodic table. As a basis for understanding this concept,

Students:

1. Relate an element's position on the periodic table to its atomic number (number of protons).
2. Relate the position of an element in the periodic table and its reactivity with other elements to its quantum electron configuration.

THE ATOM (CONTINUED)

3. Use the periodic table to compare trends in periodic properties, such as ionization energy, electronegativity, electron affinity, and relative size of atoms and ions.

4. Use an element's location in the periodic table to determine its number of valence electrons, and predict what stable ion or ions an element is likely to form in reacting with other specified elements.

Examples *Students navigate an interactive periodic table to compare chemical properties according to electron configuration (periodic.lanl.gov/default.htm) (C.5.2).*

Students role-play different atoms, stating the kinds of atoms with which they would bond, the number of electron levels, and the kinds of atoms they generally associate with. Classmates guess the atom based on the evidence presented (C.5.3).

NUCLEAR PROCESSES

C.6. Broad Concept: Nuclear processes are those in which an atomic nucleus changes; they include radioactive decay of naturally occurring and man-made isotopes and nuclear fission and fusion processes. As a basis for understanding this concept,

Students:

1. Explain how protons and neutrons in the nucleus are held together by strong nuclear forces that just balance the electromagnetic repulsion between the protons in a stable nucleus.

2. Describe that the energy release per gram of material is roughly six orders of magnitude larger in nuclear fusion or fission reactions than in chemical reactions. Know that a small decrease in mass produces a large amount of energy in nuclear reactions as well as in chemical reactions, but the mass change in chemical reactions is negligibly small.

3. Know that many naturally occurring isotopes of elements are radioactive, as are isotopes formed in nuclear reactions.

4. Describe the process of radioactive decay as the spontaneous breakdown of certain unstable (radioactive) elements into new elements (radioactive or not) through the spontaneous emission by the nucleus of alpha or beta particles, or gamma radiation.

5. Predict and explain that the alpha, beta, and gamma radiation produced in radioactive decay produce different amounts and kinds of damage in matter and have different ranges of penetration.

6. Explain that the half-life of a radioactive element is the time it takes for the radioactive element to lose one-half its radioactivity, and calculate the amount of radioactive substance remaining after an integral number of half-lives have passed.

Examples *Students design models of atoms that show the relative positions of subatomic particles (such as protons, neutrons, and electrons) using a flat aluminum pan and colored magnets (C.6.1).*

Students research numerous applications of radiocarbon dating: archaeology, Stonehenge, Dead Sea Scrolls, etc. (information is available at www.c14dating.com/applic.html) (C.6.3 and C.6.4).

Students research the effects of different types of radiation on the human body (e.g., effect of atomic bombings in WWII, nuclear waste sites, or use of radioactive drugs in medicine) (C.6.5).

CHEMICAL BONDS

C.7. Broad Concept: The enormous variety of physical, chemical, and biological properties of matter depends upon the ability of atoms to form bonds. This ability results from the electrostatic forces between electrons and protons and between atoms and molecules. As a basis for understanding this concept,

Students:

1. Explain how Arrhenius' discovery of the nature of ionic solutions contributed to the understanding of a broad class of chemical reactions.
2. Predict and explain how atoms combine to form molecules by sharing electrons to form covalent or metallic bonds, or by transferring electrons to form ionic bonds.
3. Recognize names and chemical formulas for simple molecular compounds (such as N_2O_3), ionic compounds, including those with polyatomic ions, simple organic compounds, and acids, including oxyacids (such as $HClO_4$).
4. Explain the hydrogen bond as an intermolecular attraction that can exist between a hydrogen atom on one molecule and an electronegative element like fluorine, oxygen, or nitrogen on another molecule.
5. Demonstrate and explain that chemical bonds between identical or similar atoms in molecules such as H_2, O_2, CH_4, NH_3, C_2H_4, N_2, H_2O and many large biological molecules tend to be covalent; some of these molecules may have hydrogen bonds between them. In addition, molecules have other forms of intermolecular bonds, such as London dispersion forces and/or dipole bonding.
6. Explain that in solids, particles can only vibrate around fixed positions, but in liquids, they can slide randomly past one another, and in gases, they are free to move between collisions with one another.
7. Draw Lewis dot structures for atoms, molecules, and polyatomic ions.
8. Predict the geometry and polarity of simple molecules, and explain how these influence the intermolecular attraction between molecules.
9. Predict the chemical formulas based on the number of valence electrons.
10. Predict the formulas of ionic compounds based on the charges on the ions.
11. Identify solids held together by London dispersion forces or hydrogen bonding.

Examples

Students investigate different electrolytes in the human body and the purposes they serve (C.7.1).

Students research what allows hemoglobin to hold oxygen and transport it (C.7.4).

Students freeze a sample of water with some food coloring added. They observe the ice, allow the ice to melt, and then boil the water (C.7.6).

Students illustrate the Lewis dot structures for simple carbohydrates, fats, and proteins that they will eat during the day (C.7.7).

CONSERVATION OF MATTER

C.8. Broad Concept: The microscopic conservation of atoms in chemical reactions implies the macroscopic principle of conservation of matter and the ability to calculate the mass of products and reactants. As a basis for understanding this concept,

Students:

1. Name substances and describe their reactions based on Lavoisier's system and explain how this system contributed to the rapid growth of chemistry by enabling scientists everywhere to share their findings about chemical reactions with one another without ambiguity.
2. Describe chemical reactions by writing balanced chemical equations and balancing redox equations.
3. Classify reactions of various types such as single and double replacement, synthesis, decomposition, and acid/base neutralization.
4. Calculate the masses of reactants and products in a chemical reaction from the mass of one of the reactants or products and the relevant atomic or molecular masses.
5. Calculate the percent of composition by mass of a compound when given the formula.
6. Determine molar mass of a molecule given its chemical formula and a table of atomic masses.
7. Convert the mass of a molecular substance to moles, number of particles, or volume of gas at standard temperature and pressure.
8. Use Avogadro's law to make mass-volume calculations for simple chemical reactions.
9. Define oxidation and reduction and oxidizing and reducing agents.
10. Use changes in oxidation states to recognize electron transfer reactions, and identify the substance(s) losing and gaining electrons in an electron transfer reaction.
11. Describe the effect of changes in reactant concentration, changes in temperature, the surface area of solids, and the presence of catalysts on reaction rates.

Examples

Students balance the redox reaction $U^{4+} + MnO_4^-$ Æ $UO_2^{2+} + Mn^{2+}$ *in acidic solution (C.8.2).*

Students characterize the following reactions as redox or nonredox (C.8.2):

$$2\ HCl + Al \rightarrow H_2 + AlCl_3$$
$$HCl + AgNO_3 \rightarrow HNO_3 + AgCl$$

Students classify the reactions (C.8.3):

$$2\ HBr + K_2CO_3 \rightarrow H_2O + CO_2 + 2\ KBr$$
$$H_2S + Ni(OH)_2 \rightarrow 2\ H_2O + NiS$$
$$2\ KCl + I_2 \rightarrow 2\ KI + Cl_2$$

Students determine the percent of composition of each element in $Al(NO_3)_3$ *(C.8.5).*

Students determine the molar mass of $Cu(NO_3)_2$ *(C.8.6).*

Students determine the number of atoms of oxygen in 0.5690 mol H_2O *(C.8.7).*

Students identify the reduction and oxidation in the following reaction (C.8.10):

$$Cu + NO_3^- \rightarrow Cu^{2+} + NO_2.$$

GASES AND THEIR PROPERTIES

C.9. Broad Concept: The behavior of gases can be explained by the kinetic molecular theory. As a basis for understanding this concept,

Students:

1. Explain the kinetic molecular theory and use it to explain changes in gas volumes, pressure, and temperature.
2. Apply the relationship between pressure and volume at constant temperature (Boyle's law, pV = constant at constant temperature and number of moles), and between volume and temperature (Charles' law or Gay-Lussac's law, V/T = constant at constant pressure and number of moles) and the relationship between pressure and temperature that follows from them.
3. Solve problems using the Ideal Gas law, $pV = nRT$, and the combined gas law, $p_1V_1/T_1 = p_2V_2/T_2$.
4. Apply Dalton's Law of Partial Pressures.
5. Apply Graham's Law of Diffusion.

Examples

Students relate the ideal gas law to pressure, temperature, and volume on Metro trains during rush hour (C.9.1).

Students cook hot dogs to demonstrate Charles' law on temperature-volume relationship.

Students also demonstrate Boyle's law using empty soda cans, water, and hand pressure. Students discuss and explain the analogy between Boyle's law and human breathing (C.9.2).

Students determine the molar mass of 0.650 g of O_2 *gas in 100.0 mL at STP (C.9.3).*

Students determine the total pressure of a mixture of oxygen, carbon dioxide, and helium if their partial pressures are $P_{CO2} = 0.051$ *atm,* $P_{O2} = 0.425$ *atm, and* $P_{He} = 562$ *torr (C.9.4).*

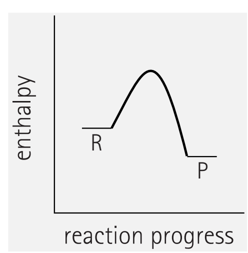
Students determine the molar mass of a molecule if it effuses at one-eighth the rate of helium (C.9.5).

CHEMICAL EQUILIBRIUM

C.10. Broad Concept: Chemical equilibrium is a dynamic process at the molecular level. As a basis for understanding this concept,

Students:

1. Explain how equilibrium is established when forward- and reverse-reaction rates are equal.
2. Describe the factors that affect the rate of a chemical reaction (temperature, concentration) and the factors that can cause a shift in equilibrium (concentration, pressure, volume, temperature).



3. Explain why rates of reaction are dependent on the frequency of collisions, energy of collisions, and orientation of colliding molecules.
4. Observe and describe the role of activation energy and catalysts in a chemical reaction.

CHEMICAL EQUILIBRIUM (CONTINUED)

5. Use LeChâtelier's principle to predict the effect of changes in concentration, temperature, volume, and pressure on a system at equilibrium.

6. Write the equilibrium expression for a given reaction and calculate the equilibrium constant for the reaction from given concentration data.

Examples *Students investigate the equilibrium of global-warming pollutants in the atmosphere, such as N_2O_4 and NO_2 (C.10.2).*

Students label the following energy profile with the ΔH, E_a and transition state (C.10.4):

Students determine the changes in the reaction if differing amounts of each chemical are added or subtracted: $CH_3OH(g) + O_2(g) \rightleftharpoons HCOOH(g) + H_2O(g)$ (C.10.5).

Students determine the equilibrium constant for a gaseous reaction (C.10.6): $2\ N_2 + O_2 \rightleftharpoons 2\ N_2O$ if, at equilibrium, 0.00340 mol N_2, 0.000452 mol O_2 and 0.540 mol N_2O are in a 1.00-L container.

SOLUTIONS

C.11. Broad Concept: Solutions are mixtures of two or more substances that are homogeneous on the molecular level. As a basis for understanding this concept,

Students:

1. Define *solute* and *solvent.*

2. Predict and describe how the temperature, concentration, pressure and surface area of solids affect the dissolving process.

3. Explain that, for a closed system at constant temperature and pressure, a solid in contact with its saturated solution may reach dynamic equilibrium when the rate of solid dissolving equals the rate of solid precipitating.

4. Calculate the concentration units of solutions such as molarity, percent by mass or volume, parts per million (ppm), or parts per billion (ppb).

5. Determine the concentration of a solution in terms of molarity and molality.

6. Calculate the theoretical freezing-point depression and boiling-point elevation of an ideal solution as a function of solute concentration.

7. Prepare a specified volume of a solution of given molarity.

8. Use titration data to calculate the concentration of an unknown solution.

Examples *Students analyze and describe what happens when increments of 5g NaCl are added to 100mL H_2O at room temperature and under heat with constant stirring (C.11.2).*

Students determine how many mg of silver nitrate are required to make 1.0 mL of 0.037 M solution (C.11.5).

Students determine the molality of a solution made by dissolving 0.1265 g $MgSO_4$ in 250.0 mL of water (C.11.5).

Students calculate the freezing point of 0.544 m $KMnO_4$(aq) using $\Delta T = K_f m$ (C.11.6).

SOLUTIONS (CONTINUED)

Students conduct titration experiments using a known concentration of an acid and an unknown concentration of a base (0.1M HCl and NaOH) and calculate the concentration of the unknown solution using the formula $c_1v_1 = c_2v_2$ *(C.11.8).*

CHEMICAL THERMODYNAMICS

C.12. Broad Concept: Energy is exchanged or transformed in all chemical reactions and physical changes of matter. As a basis for understanding this concept,

Students:

1. Describe the concepts of temperature and heat flow in terms of the motion and energy of molecules (or atoms).
2. Determine and explain that chemical processes release (exothermic) or absorb (endothermic) thermal energy.
3. Explain how energy is released when a material condenses or freezes and is absorbed when a material evaporates or melts.
4. Solve problems involving heat flow and temperature changes, using given values of specific heat and latent heat of phase change.
5. Use Hess's law to determine the heat of a reaction and to calculate enthalpy change in a reaction.

Examples *Students diagram the process of digestion. They determine times when molecules are broken down to release energy and when reactions absorb energy to be completed (C.12.2).*

Students react citric acid with baking soda, taking the temperature to show that the reaction is endothermic. Students soak steel wool in vinegar, taking the temperature to show that the reaction is exothermic (C.12.2).

Students investigate how a refrigerator or air conditioner works and why those machines produce so much carbon dioxide as a result of taking energy out/away from a more heated area (C.12.3).

Students calculate how much energy is required to melt 60.00 g water at its melting point (C.12.4).

Students calculate ΔH_{rxn} *for* $C_2H_4 + H_2O \rightarrow C_2H_6O$ *based on the following reactions (C.12.5):*

$$H_2 + C_2H_4 \rightarrow C_2H_6 \quad \Delta H = -37 \text{ kJ/mol}$$
$$2\ C_2H_6 + O_2 \rightarrow 2\ C_2H_6O \quad \Delta H = -300 \text{ kJ/mol}$$
$$2\ H_2 + O_2 \rightarrow 2\ H_2O \quad \Delta H = -572 \text{ kJ/mol}$$

ORGANIC AND BIOCHEMISTRY

C.13. Broad Concept: The bonding characteristics of carbon lead to the possibility of many different molecules of many sizes, shapes, and chemical properties. This provides the biochemical basis of life. As a basis for understanding this concept,

Students:

1. Explain how the bonding characteristics of carbon lead to a large variety of structures ranging from simple hydrocarbons to complex polymers and biological molecules.
2. Describe how large molecules (polymers) such as proteins, nucleic acids, and starch are formed by repetitive combinations of simple subunits (monomers).
3. Explain that amino acids are the building blocks of proteins.
4. Convert between chemical formulas, structural formulas, and names of simple common organic compounds (hydrocarbons, proteins, fats, carbohydrates).

Examples *Students role-play C, N, O, or H atoms. They form different compounds, based on the electron valences each atom has. Students expand to make double or triple bonds where they can (C.13.1).*

Students choose a complex biological molecule, such as hemoglobin protein or a small gene, and identify the series of monomers that link to form the longer chain (C.13.2).